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(54) OPTICAL TRACKING OF ROTOR BLADE MOTION

OPTISCHE VERFOLGUNG EINER ROTORBLATTBEWEGUNG

SUIVI OPTIQUE DE MOUVEMENT DE PALE DE ROTOR

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Description

[0001] The subject matter disclosed herein relates generally to rotary wing aircraft, and in particular to optically tracking blades of a rotary wing aircraft.

[0002] In the field of rotary wing aircraft, it is desirable to track blade motion. Rotating blades of a helicopter main rotor undergo an extremely complex motion trajectory with severe load conditions in a harsh environment. The on-board measurement of such rigid body motion at the root of the blade constitutes a major challenge for the helicopter industry. This measurement is particularly difficult for blades mounted to an elastomeric hinge-less bearing where the three angular motions (11ap, pitch and lead-lag) are highly coupled and the elastomeric bearing pivot center shifts along the blade span due to centrifugal acceleration that varies with aerodynamic load and flight regimes. Existing methods to determine the blade motion in real time and in a non-contact fashion include holographic, Morie and laser Doppler vibrometer techniques. These non-contact optical measurement methods are only able to track one degree of freedom of motion at a time and may often fail to measure both statically and dynamically. They may also be very complex, bulky and unreliable in the main rotor environment and only appropriate for the laboratory environments and wind tunnel tests. Other methods of integrating acceleration from accelerometers or gyroscopes usually require added sensors or prior knowledge of the motion characteristics to remove drift due to integration and may he incapable of measuring static and low frequency motion of the main rotor blade.

[0003] JP2010149602A and JPH10281750A disclose devices for measuring a two dimensional displacement of a rotor blade. US20100253569A1 and US20110243730A show devices for measuring the deflection of a wind turbine blade. According to US5137353A a method to improve a measuring accuracy using polarization is known.

[0004] One embodiment includes a rotary wing aircraft with an optical blade tracking system, the system including a light source generating at least one light beam, the light source coupled to a rotor blade of the rotary wing aircraft, wherein movement of the rotor blade is imparted to the light source; a two-dimensional position detector generating signals indicative of a position of the light beam along a first axis and a position of the light beam along a second axis and generating a signal indicative of an angular Position of the light beam about a third axis; a processor receiving the signals, the processor determining lead-lag, flap and pitch of the rotor blade in response to the signals; and a polarizer filter positioned between the light source and the two dimensional position detector, the polarizer filter modulating intensity of the light beam onto the two dimensional Position detector.

[0005] Particular embodiments may include any of the following optional features, alone or in combination:

The light beam may be polarized.

[0006] The two-dimensional position detector may generate an intensity signal indicative of an intensity of the light beam on the two-dimensional position detector.

[0007] The intensity signal may be indicative of an angular orientation between a light source polarization direction and a polarizer filter polarization direction.

[0008] The processor may determine lead-lag of the rotor blade as:

$$\alpha \approx c_1(V_x)$$

wherein V_x is the signal indicative of the position of the light beam along the first axis, and c_1 is a coefficient.

[0009] The processor may determine flap of the rotor blade as:

$$\beta \approx c_2 V_y$$

wherein V_y is the signal indicative of the position of the light beam along the second axis and c_2 is a coefficient.

[0010] The processor may determine pitch of the rotor blade as:

$$\theta \approx c_3 V_{IO}$$

wherein V_{IO} is the intensity signal and c_3 is a coefficient.

[0011] Another embodiment is a rotary wing aircraft with an optical blade tracking system the system including a light source generating at least one light beam, the light source coupled to a rotor blade of the rotary wing aircraft, wherein movement of the rotor blade is imparted to the light source; a two dimensional position detector generating signals indicative of a position of the light beam along a first axis and a position of the light beam along a second axis; and a processor receiving the signals, the processor determining ead-lag, flap and pitch of the rotor blade in response to the signals; wherein the at least one light beam comprises a first light beam and a second light beam generated at different times, the two dimensional position detector generated signals comprising a first signal indicative of a position of the first light beam along the first axis, a second signal indicative of a position of the first light beam along the second axis, a third signal indicative of a position of the second light beam along the first axis, and a fourth signal indicative of a position of the second light beam along the second axis.

[0012] Particular embodiments may include any of the following optional features, alone or in combination:

> The light source comprises a first light source generating the first light beam and a second light source generating the second light beam.

[0013] The optical blade tracking system further may comprise a switch to alternately provide power the first light source and the second light source.

[0014] The optical blade tracking further may comprise a shutter to alternately block an output of the first light source and the second light source.

[0015] The optical blade tracking further may comprise a positionable optical element receiving the light beam and alternately generating the first light beam and the second light beam.

[0016] The processor may determine lead-lag of the rotor blade as:

$$\alpha \approx c_1(V_{xa} + V_{xb})$$

wherein V_{xa} is the first signal indicative of the position of the first light beam along the first axis, V_{xb} is the third signal third signal indicative of the position of the second light beam along the first axis and c_1 is a coefficient.

[0017] The processor may determine flap of the rotor blade as:

$$\beta \approx c_2(V_{ya} + V_{yb})$$

wherein V_{ya} is the second signal indicative of the position of the first light beam along the second axis, V_{yb} is the fourth signal indicative of the position of the second light beam along the second axis and c_2 is a coefficient.

[0018] The processor may determine pitch of the rotor blade as:

$$\theta \approx c_3(V_{ya} - V_{yb})/(V_{xa} - V_{xb})$$

wherein V_{ya} is the second signal indicative of the position of the first light beam along the second axis, V_{yb} is the fourth signal indicative of the position of the second light beam along the second axis, V_{xa} is the first signal indicative of the position of the first light beam along the first axis, V_{xb} is the third signal third signal indicative of the position of the second light beam along the first axis and c_3 is a coefficient.

[0019] Another embodiment is a method for optical blade tracking for a rotary wing aircraft, the method including generating a first light beam and a second light beam at different times, a position of the first light beam and a position of the second light beam being responsive to movement of a rotor blade of the rotary wing aircraft; determining a position of the first light beam along a first axis, a position of the first light beam along a second axis, a position of the second light beam along the first axis, and a position of the second light beam along the second axis; determining lead-lag, flap and pitch of the rotor blade in response to the position of the first light beam along the first axis, the position of the first light beam along the second axis, the position of the second light beam along the first axis, and the position of the second light beam along the second axis.

[0020] Particular embodiments may include any of the following optional features, alone or in combination:

> Determining pitch of the rotor blade may include dividing (i) a difference between the position of the first light beam along the second axis and the position of the second light beam along the second axis by (ii) a difference between the position of the first light beam along the first axis and the position of the second light beam along the first axis.

[0021] Another embodiment is a method for optical blade tracking for a rotary wing aircraft, the method including generating a polarized light beam, a position of the polarized light beam being responsive to movement of a rotor blade of the rotary wing aircraft; determining a position of the polarized light beam along a first axis and a position of the polarized light beam along a second axis; determining a direction of polarization of the polarized light beam; determining lead-lag, flap and pitch of the rotor blade in response to the position of the polarized light beam along the first axis, the position of the polarized light beam along the second axis, and the direction of polarization of the polarized light beam. Particular embodiments may include any of the following optional features, alone or in combination:

Determining pitch of the rotor blade may include determining an angle between the direction of polarization of the polarized light beam and a predetermined direction of polarization.

[0022] Other aspects, features, and techniques of the invention will become more apparent from the following description taken in conjunction with the drawings.

[0023] Referring now to the drawings wherein like elements are numbered alike in the several FIGURES, in which:

FIG. 1 depicts a rotary wing aircraft in an exemplary embodiment;
FIG. 2 depicts a system for optically tracking blade position in an exemplary embodiment;
FIG. 3 depicts a system for optically tracking blade position using dual light beams in an exemplary embodiment;
FIG. 4 depicts a system for optically tracking blade position using a polarized light beam in an exemplary embodiment; and
FIG. 5 is a plot of light intensity versus relative polarization in an exemplary embodiment.

[0024] FIG. 1 illustrates a rotary wing aircraft 10 having a main rotor assembly 12 in an exemplary embodiment. The aircraft 10 includes an airframe 14 having an extending tail 16 which mounts a tail rotor system 18, such as an anti-torque system, a translational thrust system, a pusher propeller, a rotor propulsion system, and the like. The main rotor assembly 12 is driven about an axis of rotation R through a main gearbox (illustrated schematically at 20) by one or more engines 22. The main rotor assembly 12 includes a plurality of rotor blades 24 mounted to a rotor hub 26. Although a particular rotary wing aircraft configuration is illustrated, other configurations and/or machines, such as high speed compound rotary wing aircraft with supplemental translational thrust systems, dual contra-rotating aircraft, coaxial rotor system aircraft, turbo-props, tilt-rotors and tilt-wing aircraft, will also benefit from embodiments of the invention.

[0025] FIG. 2 depicts a system for optically tracking blade position in an exemplary embodiment. Shown in FIG. 2 is a rotor blade spindle 30 mounted to an elastomeric bearing 32. A pivot center of the elastomeric bearing 32 is shown by axis A. A light source 34 is mounted to the blade spindle 30. Other mounting or positioning arrangements may be used so that light source 34 moves with movement of rotor blade 24 coupled to spindle 30. It is understood that light source 34 may be mounted to components other than spindle 30. Light source 34 may be any known type of light source, such as a laser diode. The term "light" is used herein to refer to any frequency so that visible and non-visible wavelengths may be generated by light source 34.

[0026] A position detector 36 receives light from light source 34 and generates position signals indicative of a location of a light beam from light source 34 relative to reference axes of the position detector 36. Position detector 36 is described in further detail herein with reference to FIGs. 3 and 4. A processor 38 receives output signals from the position detector 36 and computes one or more of lead-lag, flap and pitch of rotor blade 24 coupled to blade spindle 30. Processor 38 may be implemented using a general-purpose microprocessor executing a computer program to perform the operations described herein. Processor 38 may be implemented using hardware (e.g., ASIC, FPGA) and/or a combination of hardware and software.

[0027] FIG. 3 depicts a system for optically tracking blade position using dual light beams in an exemplary embodiment. In the embodiment of FIG. 3, two lights sources 42 and 44 are mounted to blade spindle 30. Light sources 42 and 44 may be laser diodes separated by a small angle, with each laser diode directed at position detector 36.

[0028] Position detector 36 is a two-dimensional position sensitive detector (2D PSD) that receives a light beam and outputs a voltage (Vx and Vy) proportional to x and y coordinates of the beam spot on the position detector 36. Position detector 36 may be mounted on the rotor hub.

[0029] As the position detector 36 only generates x and y coordinates for a single point, the light sources 42 and 44 are switched on and off, alternately, so that the instantaneous voltage outputs (Vx and Vy) of the position detector 36 represent the x and y coordinates along the x and y axes of the spot being currently illuminated. An alternating switch 50 is used to alternately provide power from power source 52 to the light sources 42 and 44. In this manner, only one of light source 42 and 44 produces a light beam at a time. The switch 50 may be controlled by processor 38, so that the processor 38 can synchronize the output signals from the position detector 36 with one of the light beams generated by light sources 42 and 44.

[0030] From the output signals of the position detector 36, processor 38 determines lead-lag, flap and pitch of rotor blade 24 mounted to spindle 30. The three angular motions of the blade spindle 30 can be calculated from the measured voltage outputs from the position detector 36 as shown below.

Lead - lag

$$\alpha = a\tan((x_a + x_b)/(2L)) \approx (x_a + x_b)/(2L) = c_1(V_{xa} + V_{xb})$$

Flap

$$\beta = a\tan((y_a + y_b)/(2L)) \approx (y_a + y_b)/(2L) = c_2(V_{ya} + V_{yb})$$

Pitch

$$\theta = a\tan((y_b - y_a)/(x_b - x_a)) \approx c_3(V_{ya} - V_{yb})/(V_{xa} - V_{xb})$$

[0031] In the above equations, the notations a and b represent the two light sources 42 and 44, respectively. The value L is the distance from the position detector 36 to the pivot axis of the blade spindle 30. Coefficients c_1, c_2 and c_3 are used to approximate the lead-lag, flap and pitch, respectively.

[0032] The angular motions of flap and lead-lag are linearly determined by the average x and y coordinates of the two laser spots, respectively. The pitch motion is calculated based on the difference of two sets of the coordinates. The embodiment of FIG. 3 provides a direct measurement (each motion is proportional to the voltages) without need for computational conversion. The measurements of the three angular motions are also immune to the shift of the elastomeric bearing pivot center due to various centrifugal loading (e.g., x and y coordinates change with shift in distance L).

[0033] In the embodiment of FIG. 3, two light beams are produced by alternately powering a first light source 42 and a second light source 44. It is understood that other techniques may be employed to generate the two light beams. For example, in an alternative embodiment both light sources 42 and 44 are constantly powered, and a shutter is alternately positioned to block one of the two light sources. The shutter may be controlled by processor 38, so that the processor 38 can synchronize the output signals from the position detector 36 with one of the light beams generated by light sources 42 and 44. In another embodiment, a single light source is used and a positionable optical element (e.g., prism, lens system) is used to generate two light beams having the desired angular relationship. The optical element may be controlled by processor 38, so that the processor 38 can synchronize the output signals from the position detector 36 with one of the light beams generated by the optical element.

[0034] FIG. 4 depicts a system for optically tracking blade position using a polarized light beam in an exemplary embodiment. As shown in FIG. 4, a single light source 60 (e.g., a laser diode) is mounted to blade spindle 30. Light source 60 outputs a collimated, polarized light beam. Position detector 62 is a two-dimensional position sensitive detector (2D PSD) that receives a light beam and outputs a voltage (Vx and Vy) proportional to x and y coordinates along the x and y axes of the beam spot on the detector 62. Position detector 62 also generates an intensity output V_{IO} that is proportional to an intensity of the light beam on the position detector 62. Position detector 36 may be mounted on the rotor hub. A polarizing filter 64 is positioned in front of the position detector 60.

[0035] The x and y coordinates from position detector 62 provide for computation of lead-lag and flap. The use of a polarized light beam and polarizing filter 64 make it possible to determine pitch. When position detector 62 with polarizer filter 64 receives a polarized light beam, the intensity of the light beam impinging position detector 62 is modulated by the relative orientation of the light source polarization direction and the polarizer filter polarization direction. This is represented in the intensity output V_{IO}. The intensity of the polarized light passing through the polarizing filter 64 varies between zero and maximum as the light source 60 rotates with respect to the polarizer filter 64 from 90 degrees to 0 degrees. FIG. 5 illustrates light intensity at the position detector 62 versus relative angle between the polarization direction of the light source 60 and polarization direction polarization filter 64. Therefore, the position detector 62 intensity output is representative of the pitch angle (rotation about z axis) of blade 24.

[0036] The three angular motions of the blade spindle 30 can be calculated from the measured voltage outputs from the position detector 62 as shown below.

Lead - lag

$$\alpha = a\tan(x/L) \approx x/L = c_1 V_x$$

Flap

$$\beta = a\tan(y/L) \approx y/L = c_2 V_y$$

Pitch

$$\theta = bI_0 \cos^2(\theta) \approx c_3 I_0 \theta = c_3 V_{I0}$$

[0037] In the above equations, the value L is the distance from the position detector 62 to the pivot axis of the blade spindle 30. Coefficients c_1, c_2 and c_3 are used to approximate the lead-lag, flap and pitch, respectively.

[0038] The embodiment of FIG. 4 provides a direct measurement (each motion is proportional to the voltage) without need for computational conversion. The measurement of the three angular motions is also immune to the shift of the elastomeric bearing pivot center due various centrifugal loading (e.g., x and y coordinates change with shift in distance L).

[0039] Embodiments provide three degrees of angular motion measurement simultaneously using one sensor. This provides for dynamic and static measurements with the same level of accuracy. The measurements are immune to shifts of the elastomeric bearing pivot center due aerodynamic and/or centrifugal loading. Direct measurements of angular motions are provided with minimal computation requirements.

[0040] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. While the description of the present invention has been presented for purposes of illustration and description, it is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications, variations, alterations, substitutions, or equivalent arrangement not hereto described will be apparent to those of ordinary skilled in the art.

[0041] Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

Claims

1. A rotary wing aircraft (10) with an optical blade tracking system, the system comprising: a light source (34; 60) generating at least one light beam, the light source (34) coupled to a rotor blade (24) of the rotary wing aircraft (10), wherein movement of the rotor blade is imparted to the light source (34); a two-dimensional position detector (62) generating signals indicative of a position of the light beam along a first axis and a position of the light beam along a second axis and generating a signal indicative of an angular position of the light beam about a third axis; a processor (38) receiving the signals, **characterized in that** the processor (38) determines lead-lag, flap and pitch of the rotor blade in response to the signals; and **in that** the systen further comprises a polarizer filter (64) positioned between the light source and the two dimensional position detector, the polarizer filter (64) modulating intensity of the light beam onto the two-dimensional position detector (62).

2. The rotary wing aircraft (10) of claim 1, wherein: the light beam is polarized; and/or wherein: the two-dimensional position detector (62) generates an intensity signal indicative of an intensity of the light beam on the two-dimensional position detector (62); and/or wherein: the intensity signal is indicative of an angular orientation between a light source polarization direction and a polarizer filter polarization direction.

3. The rotary wing aircraft (10) of claim 1 or 2, wherein:

   the processor (38) determines lead-lag of the rotor blade as:

$$\alpha \approx c_1(V_x)$$

wherein V_x is the signal indicative of the position of the light beam along the first axis, and c_1 is a coefficient.

4. The rotary wing aircraft (10) of any of claims 1 to 3, wherein the processor (38) determines flap of the rotor blade as:

$$ß \approx c_2 V_y$$

wherein V_y is the signal indicative of the position of the light beam along the second axis and c_2 is a coefficient.

5. The rotary wing aircraft (10) of any of claims 1 to 4, wherein: the processor determines pitch of the rotor blade as:

$$\Theta \approx c_3 V_{10}$$

wherein V_{10} is the intensity signal and c_3 is a coefficient.

6. A rotary wing aircraft (10) comprising an optical blade tracking system wherein the tracking system is comprising: a light source (34) generating at least one light beam, the light source (34) coupled to a rotor blade (24) of the rotary wing aircraft (10), wherein movement of the rotor blade (24) is imparted to the light source (34); a two-dimensional position detector (36) generating signals indicative of a position of the light beam along a first axis and a position of the light beam along a second axis; and a processor (38) receiving the signals, wherein the at least one light beam comprises a first light beam and a second light beam generated at different times, the two-dimensional position detector generated signals comprising a first signal indicative of a position of the first light beam along the first axis, a second signal indicative of a position of the first light beam along the second axis, a third signal indicative of a position of the second light beam along the first axis, and a fourth signal indicative of a position of the second light beam along the second axis **characterized in that** the processor (38) determines lead-lag, flap and pitch of the rotor blade (24) in response to the signals and **in that** the light source (34) comprises a first light source (42) generating the first light beam and a second light source (44) generating the second light beam; and/or further comprising: a switch (50) to alternately provide power to the first light source and the second light source (44); and/or further comprising: a shutter to alternately block an output of the first light source and the second light source.

7. The rotary wing aircraft (10) of claim 5 or 6, further comprising: a positionable optical element receiving the light beam and alternately generating the first light beam and the second light beam.

8. The rotary wing aircraft (10) of any of claims 5 to 7, wherein: the processor (38) determines lead-lag of the rotor blade (24) as:

$$\alpha \approx c_1(V_{xa} + V_{xb})$$

wherein V_{xa} is the first signal indicative of the position of the first light beam along the first axis, V_{xb} is the third signal third signal indicative of the Position of the second light beam along the first axis and ci is a coefficient.

9. The rotary wing aircraft (10) of any of claims 5 to 8, wherein: the processor determines flap of the rotor blade as:

$$\beta \approx c_2(V_{ya} + V_{yb})$$

wherein V_{ya} is the second signal indicative of the position of the first light beam along the second axis, V_{yb} is the fourth signal indicative of the position of the second light beam along the second axis and c_2 is a coefficient.

10. The rotary wing aircraft (10) of any of claims 5 to 9, wherein: the processor (38) determines pitch of the rotor blade as:

$$\Theta \approx c_3(V_{ya} - V_{yb}) / (V_{xa} - V_{xb})$$

wherein V_{ya} is the second signal indicative of the position of the first light beam along the second axis, V_{yb} is the fourth signal indicative of the position of the second light beam along the second axis, V_{xa} is the first signal indicative of the position of the first light beam along the first axis, V_{xb} is the third signal third signal indicative of the position of the second light beam along the first axis and c_3 is a coefficient.

11. A method for optical blade tracking for a rotary wing aircraft (10), the method comprising: generating a first light beam by a first light source (42) and a second light beam by a second light source (44) at different times, a position of the first light beam and a position of the second light beam being responsive to movement of a rotor blade of the rotary wing aircraft;
determining a position of the first light beam along a first axis; a position of the first light beam along a second axis, a position of the second light beam along the first axis, and a position of the second light beam along the second axis;
determining lead-lag, flap and pitch of the rotor blade in response to the position of the first light beam along the first axis, the position of the first light beam along the second axis, the position of the second light beam along the first axis, and the position of the second light beam along the second axis.

12. The method of claim 11 wherein:

determining pitch of the rotor blade (24) includes dividing

(i) a difference between the position of the first light beam along the second axis and the position of the second light beam along the second axis by
(ii) a difference between the position of the first light beam along the first axis and the position of the second light beam along the first axis.

13. A method for optical blade tracking for a rotary wing aircraft, the method comprising: generating a polarized light beam, a position of the polarized light beam being responsive to movement of a rotor blade of the rotary wing aircraft;
determining a position of the polarized light beam along a first axis and a position of
the polarized light beam along a second axis;
determining a direction of polarization of the polarized light beam; determining lead-lag, flap and pitch of the rotor blade in response to the position of the polarized light beam along the first axis, the position of the polarized light beam along the second axis, and the direction of polarization of the polarized light beam.

14. The method of claim 13 wherein:

determining pitch of the rotor blade includes determining an angle (α) between the direction of polarization of the polarized light beam and a predetermined direction of polarization.

Patentansprüche

1. Drehflügelluftfahrzeug (10) mit einem optischen Blattverfolgungssystem, wobei das System Folgendes umfasst: eine Lichtquelle (34; 60), die mindestens einen Lichtstrahl erzeugt, wobei die Lichtquelle (34) mit einem Rotorblatt (24) des Drehflügelluftfahrzeugs (10) gekoppelt ist, wobei eine Bewegung des Rotorblatts an die Lichtquelle (34) weitergegeben wird; einen zweidimensionalen Positionsdetektor (62), der Signale erzeugt, die eine Position des Lichtstrahls entlang einer ersten Achse und eine Position des Lichtstrahls entlang einer zweiten Achse anzeigen, und der ein Signal erzeugt, das eine Winkelposition des Lichtstrahls um eine dritte Achse anzeigt; einen Prozessor (38), der die Signale empfängt, **dadurch gekennzeichnet, dass** der Prozessor (38) Schwenken, Schlagen und Verstellung des Rotorblatts als Reaktion auf die Signale bestimmt; und dadurch, dass das System ferner ein Polarisationsfilter (64) umfasst, das zwischen der Lichtquelle und dem zweidimensionalen Positionsdetektor positioniert ist, wobei das Polarisationsfilter (64) die Intensität des Lichtstrahls auf den zweidimensionalen Positionsdetektor (62) moduliert.

2. Drehflügelluftfahrzeug (10) nach Anspruch 1, wobei: der Lichtstrahl polarisiert ist; und/oder wobei: der zweidimensionale Positionsdetektor (62) ein Intensitätssignal erzeugt, das eine Intensität des Lichtstrahls auf dem zweidimensionalen Positionsdetektor (62) anzeigt; und/oder wobei: das Intensitätssignal eine Winkelausrichtung zwischen einer Lichtquellen-Polarisationsrichtung und einer Polarisationsfilter-Polarisationsrichtung anzeigt.

3. Drehflügelluftfahrzeug (10) nach Anspruch 1 oder 2, wobei:

der Prozessor (38) das Schwenken des Rotorblatts als Folgendes bestimmt:

$$\alpha \approx c_1(V_x),$$

wobei V_x das Signal ist, das die Position des Lichtstrahls entlang der ersten Achse anzeigt, und c_1 ein Koeffizient ist.

4. Drehflügelluftfahrzeug (10) nach einem der Ansprüche 1 bis 3, wobei der Prozessor (38) das Schlagen des Rotorblatts als Folgendes bestimmt:

$$\beta \approx c_2 V_y,$$

wobei V_y das Signal ist, das die Position des Lichtstrahls entlang der zweiten Achse anzeigt, und c_2 ein Koeffizient ist.

5. Drehflügelluftfahrzeug (10) nach einem der Ansprüche 1 bis 4, wobei: der Prozessor die Verstellung des Rotorblatts als Folgendes bestimmt:

$$\theta \approx c_3 V_{10},$$

wobei V_{10} das Intensitätssignal ist und c_3 ein Koeffizient ist.

6. Drehflügelluftfahrzeug (10), umfassend ein optisches Blattverfolgungssystem, wobei das Verfolgungssystem Folgendes umfasst: eine Lichtquelle (34), die mindestens einen Lichtstrahl erzeugt, wobei die Lichtquelle (34) mit einem Rotorblatt (24) des Drehflügelluftfahrzeugs (10) gekoppelt ist, wobei eine Bewegung des Rotorblatts (24) an die Lichtquelle (34) weitergegeben wird;
einen zweidimensionalen Positionsdetektor (36), der Signale erzeugt, die eine Position des Lichtstrahls entlang einer ersten Achse und eine Position des Lichtstrahls entlang einer zweiten Achse anzeigen; und einen Prozessor (38), der die Signale empfängt, wobei der mindestens eine Lichtstrahl einen ersten Lichtstrahl und einen zweiten Lichtstrahl umfasst, die zu unterschiedlichen Zeitpunkten erzeugt werden, wobei die von dem zweidimensionalen Positionsdetektor erzeugten Signale ein erstes Signal, das eine Position des ersten Lichtstrahls entlang der ersten Achse anzeigt, ein zweites Signal, das eine Position des ersten Lichtstrahls entlang der zweiten Achse anzeigt, ein drittes Signal, das eine Position des zweiten Lichtstrahls entlang der ersten Achse anzeigt, und ein viertes Signal umfassen, das eine Position des zweiten Lichtstrahls entlang der zweiten Achse anzeigt, **dadurch gekennzeichnet, dass** der Prozessor (38) Schwenken, Schlagen und Verstellung des Rotorblatts (24) als Reaktion auf die Signale bestimmt, und dadurch, dass die Lichtquelle (34) eine erste Lichtquelle (42), die den ersten Lichtstrahl erzeugt, und eine zweite Lichtquelle (44) umfasst, die den zweiten Lichtstrahl erzeugt; und/oder ferner umfassend: einen Schalter (50), um abwechselnd der ersten Lichtquelle und der zweiten Lichtquelle (44) Strom zuzuführen; und/oder ferner umfassend: eine Abblendvorrichtung, um abwechselnd eine Ausgabe von der ersten Lichtquelle und der zweiten Lichtquelle zu blockieren.

7. Drehflügelluftfahrzeug (10) nach Anspruch 5 oder 6, ferner umfassend: ein positionierbares optisches Element, das den Lichtstrahl empfängt und abwechselnd den ersten Lichtstrahl und den zweiten Lichtstrahl erzeugt.

8. Drehflügelluftfahrzeug (10) nach einem der Ansprüche 5 bis 7, wobei: der Prozessor (38) das Schwenken des Rotorblatts (24) als Folgendes bestimmt:

$$\alpha \approx c_1(V_{xa} + V_{xb}),$$

wobei V_{xa} das erste Signal ist, das die Position des ersten Lichtstrahls entlang der ersten Achse anzeigt, V_{xb} das dritte Signal ist, das die Position des zweiten Lichtstrahls entlang der ersten Achse anzeigt, und c_1 ein Koeffizient ist.

9. Drehflügelluftfahrzeug (10) nach einem der Ansprüche 5 bis 8, wobei: der Prozessor das Schlagen des Rotorblatts als Folgendes bestimmt:

$$\beta \approx c_2(V_{ya} + V_{yb}),$$

wobei V_{ya} das zweite Signal ist, das die Position des ersten Lichtstrahls entlang der zweiten Achse anzeigt, V_{yb} das vierte Signal ist, das die Position des zweiten Lichtstrahls entlang der zweiten Achse anzeigt, und c_2 ein Koeffizient ist.

10. Drehflügelluftfahrzeug (10) nach einem der Ansprüche 5 bis 9, wobei: der Prozessor (38) die Verstellung des Rotorblatts als Folgendes bestimmt:

$$\theta \approx c_3(V_{ya} - V_{yb}) / (V_{xa} - V_{xb}),$$

wobei V_{ya} das zweite Signal ist, das die Position des ersten Lichtstrahls entlang der zweiten Achse anzeigt, V_{yb} das vierte Signal ist, das die Position des zweiten Lichtstrahls entlang der zweiten Achse anzeigt, V_{xa} das erste Signal ist, das die Position des ersten Lichtstrahls entlang der ersten Achse anzeigt, V_{xb} das dritte Signal ist, das die Position des zweiten Lichtstrahls entlang der ersten Achse anzeigt, und c_3 ein Koeffizient ist.

11. Verfahren zur optischen Blattverfolgung für ein Drehflügelluftfahrzeug (10), wobei das Verfahren Folgendes umfasst:
Erzeugen eines ersten Lichtstrahls durch eine erste Lichtquelle (42) und eines zweiten Lichtstrahls durch eine zweite Lichtquelle (44) zu unterschiedlichen Zeitpunkten, wobei eine Position des ersten Lichtstrahls und eine Position des zweiten Lichtstrahls auf eine Bewegung eines Rotorblatts des Drehflügelluftfahrzeugs reagieren;
Bestimmen einer Position des ersten Lichtstrahls entlang einer ersten Achse, einer Position des ersten Lichtstrahls entlang einer zweiten Achse, einer Position des zweiten Lichtstrahls entlang der ersten Achse und einer Position des zweiten Lichtstrahls entlang der zweiten Achse;
Bestimmen von Schwenken, Schlagen und Verstellung des Rotorblatts als Reaktion auf die Position des ersten Lichtstrahls entlang der ersten Achse, die Position des ersten Lichtstrahls entlang der zweiten Achse, die Position des zweiten Lichtstrahls entlang der ersten Achse und die Position des zweiten Lichtstrahls entlang der zweiten Achse.

12. Verfahren nach Anspruch 11, wobei:

das Bestimmen der Verstellung des Rotorblatts (24) das Teilen (i) einer Differenz zwischen der Position des ersten Lichtstrahls entlang der zweiten Achse und der Position des zweiten Lichtstrahls entlang der zweiten Achse durch
(ii) eine Differenz zwischen der Position des ersten Lichtstrahls entlang der ersten Achse und der Position des zweiten Lichtstrahls entlang der ersten Achse einschließt.

13. Verfahren zur optischen Blattverfolgung für ein Drehflügelluftfahrzeug, wobei das Verfahren Folgendes umfasst:
Erzeugen eines polarisierten Lichtstrahls, wobei eine Position des polarisierten Lichtstrahls auf eine Bewegung eines Rotorblatts des Drehflügelluftfahrzeugs reagiert;
Bestimmen einer Position des polarisierten Lichtstrahls entlang einer ersten Achse und einer Position des polarisierten Lichtstrahls entlang einer zweiten Achse;
Bestimmen einer Polarisationsrichtung des polarisierten Lichtstrahls;
Bestimmen von Schwenken, Schlagen und Verstellung des Rotorblatts als Reaktion auf die Position des polarisierten Lichtstrahls entlang der ersten Achse, die Position des polarisierten Lichtstrahls entlang der zweiten Achse und Polarisationsrichtung des polarisierten Lichtstrahls.

14. Verfahren nach Anspruch 13, wobei:

das Bestimmen der Verstellung des Rotorblatts das Bestimmen eines Winkels (α) zwischen der Polarisationsrichtung des polarisierten Lichtstrahls und einer vorher festgelegten Polarisationsrichtung einschließt.

Revendications

1. Aéronef à voilure tournante (10) avec un système de suivi de pale optique, le système comprenant : une source de lumière(34 ; 60) générant au moins un faisceau lumineux, la source de lumière (34) étant couplée à une pale de rotor (24) de l'aéronef à voilure tournante (10), dans lequel le mouvement de la pale de rotor est communiqué à la source de lumière (34) ; un détecteur de position bidimensionnel (62) générant des signaux indiquant une position du faisceau lumineux le long d'un premier axe et une position du faisceau lumineux le long d'un deuxième axe et générant un signal indiquant une position angulaire du faisceau lumineux autour d'un troisième axe ; un processeur (38) recevant les signaux, **caractérisé en ce que** le processeur (38) détermine la trainée, le battement et le pas de la pale de rotor en réponse aux signaux ; et **en ce que** le système comprend en outre un filtre polariseur (64) positionné entre la source de lumière et le détecteur de position bidimensionnel, le filtre polariseur (64) modulant l'intensité du faisceau lumineux sur le détecteur de position bidimensionnel (62).

2. Aéronef à voilure tournante (10) selon la revendication 1, dans lequel : le faisceau lumineux est polarisé ; et/ou dans lequel : le détecteur de position bidimensionnel (62) génère un signal d'intensité indiquant une intensité du faisceau lumineux sur le détecteur de position bidimensionnel (62) ; et/ou dans lequel : le signal d'intensité indique une orientation angulaire entre une direction de polarisation de la source de lumière et une direction de polarisation du filtre polariseur.

3. Aéronef à voilure tournante (10) selon la revendication 1 ou 2, dans lequel :

   le processeur (38) détermine la trainée de la pale de rotor comme :

   $$\alpha \approx c_1 (V_x)$$

   dans lequel V_x est le signal indiquant la position du faisceau lumineux le long du premier axe, et c_1 est un coefficient.

4. Aéronef à voilure tournante (10) selon l'une quelconque des revendications 1 à 3, dans lequel le processeur (38) détermine le battement de la pale de rotor comme :

   $$\beta \approx c_2 V_y$$

   dans lequel V_y est le signal indiquant la position du faisceau lumineux le long du deuxième axe et c_2 est un coefficient.

5. Aéronef à voilure tournante (10) selon l'une quelconque des revendications 1 à 4, dans lequel : le processeur détermine le pas de la pale de rotor comme :

   $$\theta \approx c_3 V_{10}$$

   dans lequel V_{10} est le signal d'intensité et c_3 est un coefficient.

6. Aéronef à voilure tournante (10) comprenant un système de suivi de pale optique dans lequel le système de suivi comprend :

   une source de lumière (34) générant au moins un faisceau lumineux, la source de lumière (34) étant couplée à une pale de rotor (24) de l'aéronef à voilure tournante (10), dans lequel le mouvement de la pale de rotor (24) est communiqué à la source de lumière (34) ;
   un détecteur de position bidimensionnel (36) générant des signaux indiquant une position du faisceau lumineux le long d'un premier axe et une position du faisceau lumineux le long d'un deuxième axe ; et un processeur (38) recevant les signaux, dans lequel l'au moins un faisceau lumineux comprend un premier faisceau lumineux et un deuxième faisceau lumineux générés à différents moments, les signaux générés par le détecteur de position bidimensionnel comprenant un premier signal indiquant une position du premier faisceau lumineux le

5 long du premier axe, un deuxième signal indiquant une position du premier faisceau lumineux le long du deuxième axe, un troisième signal indiquant une position du deuxième faisceau lumineux le long du premier axe, et un quatrième signal indiquant une position du deuxième faisceau lumineux le long du deuxième axe **caractérisé en ce que** le processeur (38) détermine la trainée, le battement et le pas de la pale de rotor (24) en réponse aux signaux et **en ce que** la source de lumière (34) comprend une première source de lumière (42) générant le premier faisceau lumineux et une deuxième source de lumière (44) générant le deuxième faisceau lumineux ; et/ou comprenant en outre : un interrupteur (50) pour fournir alternativement du courant à la première source de lumière et à la deuxième source de lumière (44) ; et/ou comprenant en outre : un obturateur pour bloquer alternativement une sortie de la première source de lumière et de la deuxième source de lumière.

7. Aéronef à voilure tournante (10) selon la revendication 5 ou 6, comprenant en outre : un élément optique positionnable recevant le faisceau lumineux et générant alternativement le premier faisceau lumineux et le deuxième faisceau lumineux.

8. Aéronef à voilure tournante (10) selon l'une quelconque des revendications 5 à 7, dans lequel : le processeur (38) détermine la trainée de la pale de rotor (24) comme :

$$\alpha \approx c_1(V_{xa} + V_{xb})$$

dans lequel V_{xa} est le premier signal indiquant la position du premier faisceau lumineux le long du premier axe, V_{xb} est le troisième signal troisième signal indiquant la position du deuxième faisceau lumineux le long du premier axe et c_1 est un coefficient.

9. Aéronef à voilure tournante (10) selon l'une quelconque des revendications 5 à 8, dans lequel : le processeur détermine le battement de la pale de rotor comme :

$$\beta \approx c_2(V_{ya} + V_{yb})$$

dans lequel V_{ya} est le deuxième signal indiquant la position du premier faisceau lumineux le long du deuxième axe, V_{yb} est le quatrième signal indiquant la position du deuxième faisceau lumineux le long du deuxième axe et c_2 est un coefficient.

10. Aéronef à voilure tournante (10) selon l'une quelconque des revendications 5 à 9, dans lequel : le processeur (38) détermine le pas de la pale de rotor comme :

$$\theta \approx c_3(V_{ya} - V_{yb}) \ / \ (V_{xa} - V_{xb})$$

dans lequel V_{ya} est le deuxième signal indiquant la position du premier faisceau lumineux le long du deuxième axe, V_{yb} est le quatrième signal indiquant la position du deuxième faisceau lumineux le long du deuxième axe, V_{xa} est le premier signal indiquant la position du premier faisceau lumineux le long du premier axe, V_{xb} est le troisième signal troisième signal indiquant la position du deuxième faisceau lumineux le long du premier axe et c_3 est un coefficient.

11. Procédé de suivi de pale optique pour un aéronef à voilure tournante (10), le procédé comprenant : la génération d'un premier faisceau lumineux par une première source de lumière (42) et d'un deuxième faisceau lumineux par une deuxième source de lumière (44) à différents moments, une position du premier faisceau lumineux et une position du deuxième faisceau lumineux étant la réponse au mouvement d'une pale de rotor de l'aéronef à voilure tournante ;
détermination d'une position du premier faisceau lumineux le long d'un premier axe ; d'une position du premier faisceau lumineux le long d'un deuxième axe ; d'une position du deuxième faisceau lumineux le long du premier axe ; d'une position du deuxième faisceau lumineux le long du deuxième axe ;
détermination de la trainée, du battement et du pas de la pale de rotor en réponse à la position du premier faisceau lumineux le long du premier axe, à la position du premier faisceau lumineux le long d'un deuxième axe, à la position du deuxième faisceau lumineux le long du premier axe et à la position du deuxième faisceau lumineux le long du

deuxième axe.

12. Procédé selon la revendication 11 dans lequel :

la détermination du pas de la pale de rotor (24) comprend la division

(i) d'une différence entre la position du premier faisceau lumineux le long du deuxième axe et la position du deuxième faisceau lumineux le long du deuxième axe par
(ii) une différence entre la position du premier faisceau lumineux le long du premier axe et la position du deuxième faisceau lumineux le long du premier axe.

13. Procédé de suivi de pale optique pour un aéronef à voilure tournante, le procédé comprenant : la génération d'un faisceau lumineux polarisé, d'une position du faisceau lumineux polarisé en réponse au mouvement d'une pale de rotor de l'aéronef à voilure tournante ;
détermination d'une position du faisceau lumineux polarisé le long d'un premier axe et d'une position du faisceau lumineux polarisé le long d'un deuxième axe ;
détermination d'une direction de polarisation du faisceau lumineux polarisé ;
détermination de la trainée, du battement et du pas de la pale de rotor en réponse à la position du faisceau lumineux polarisé le long du premier axe, à la position du faisceau lumineux polarisé le long du deuxième axe, et la direction de polarisation du faisceau lumineux polarisé.

14. Procédé selon la revendication 13 dans lequel :

la détermination du pas de la pale de rotor comprend la détermination d'un angle (α) entre la direction de polarisation du faisceau lumineux polarisé et une direction de polarisation prédéterminée.

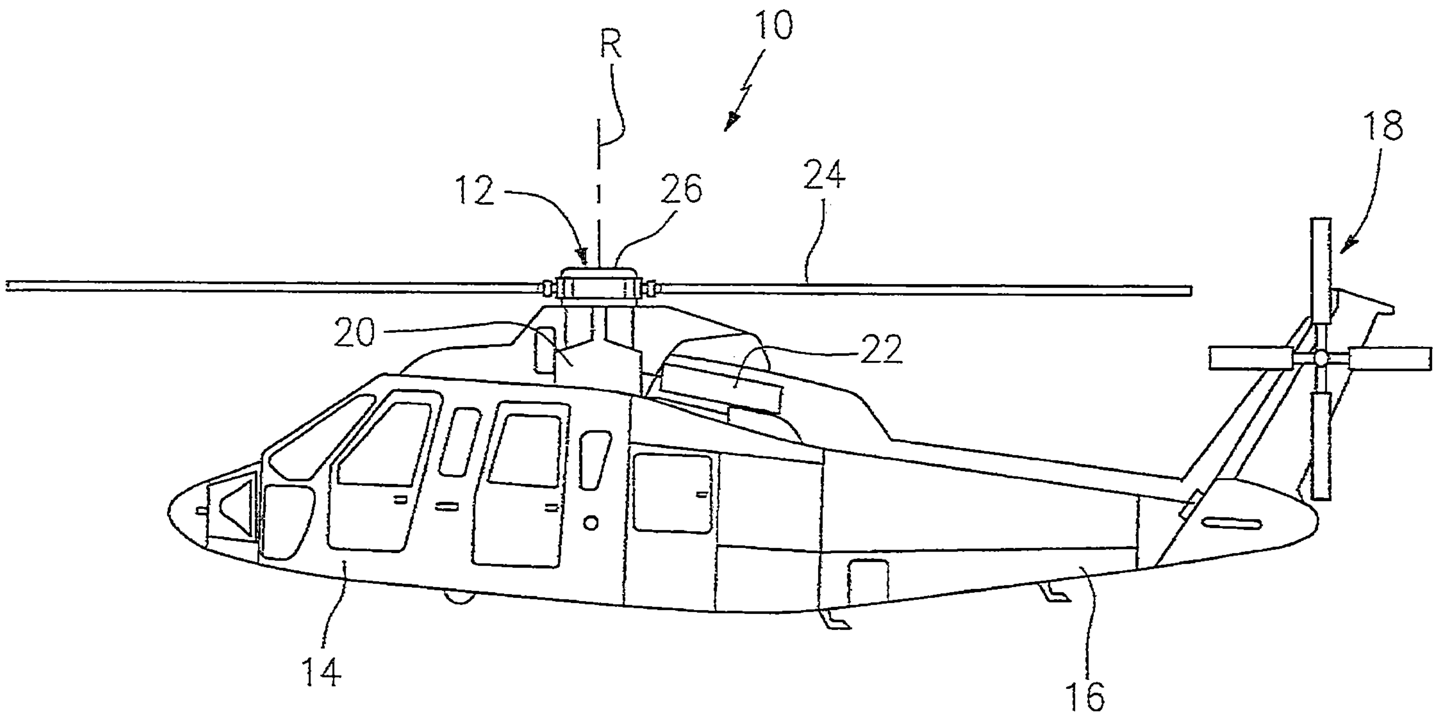

FIG. 1

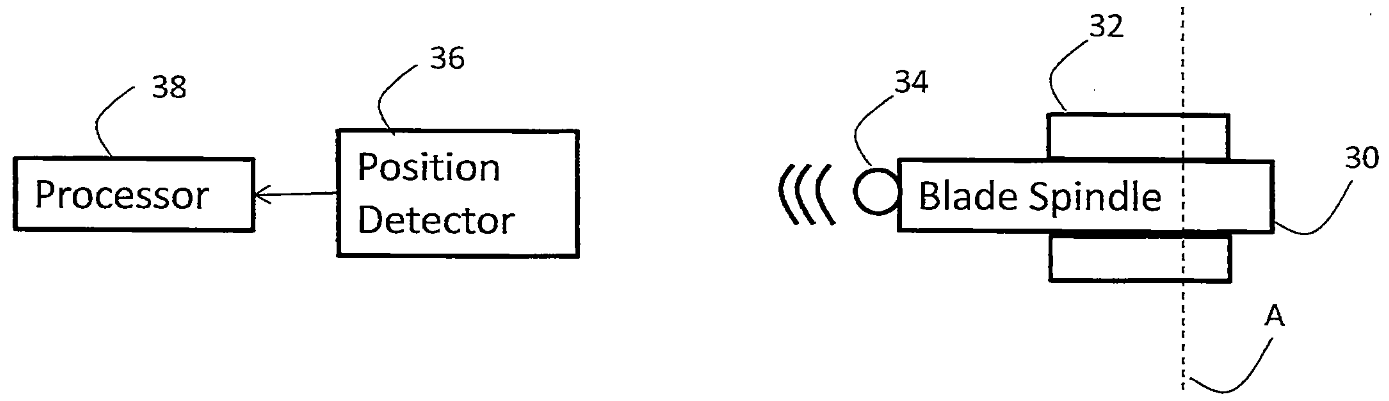

FIG. 2

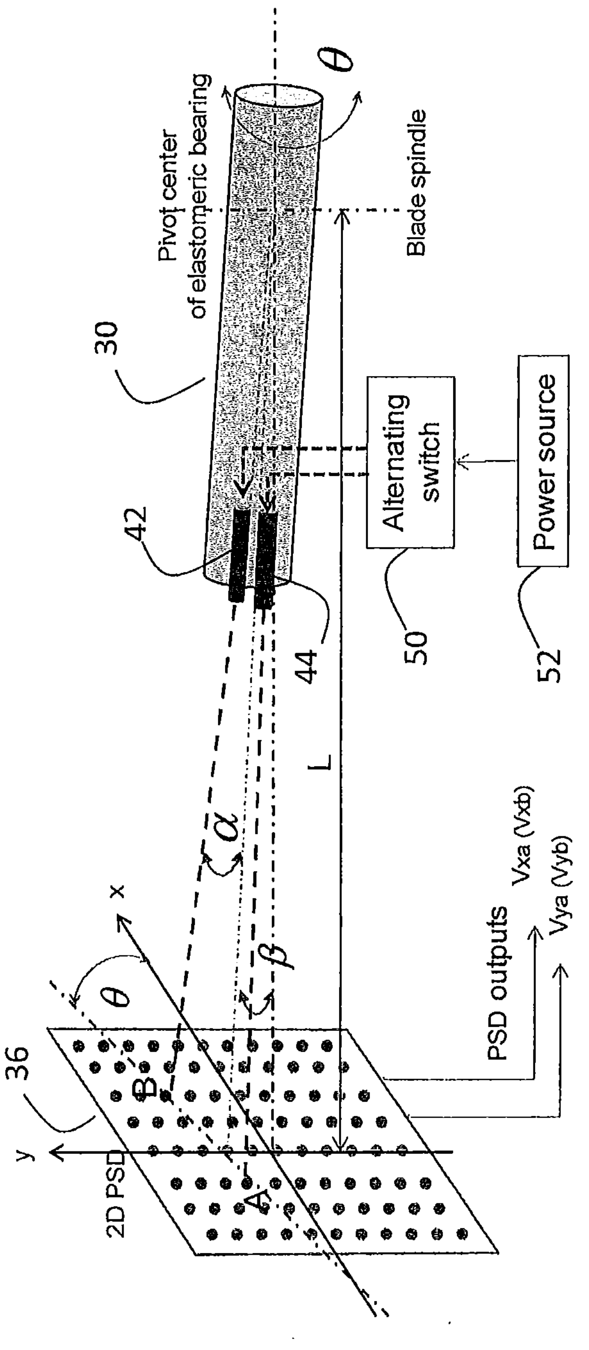
30
Pivot center
of elastomeric bearing
Blade spindle
θ
42
44
Alternating
switch
Power source
50
52
L
α
β
θ
x
y
36
2D PSD
A
B
PSD outputs
Vxa (Vxb)
Vya (Vyb)

FIG. 3

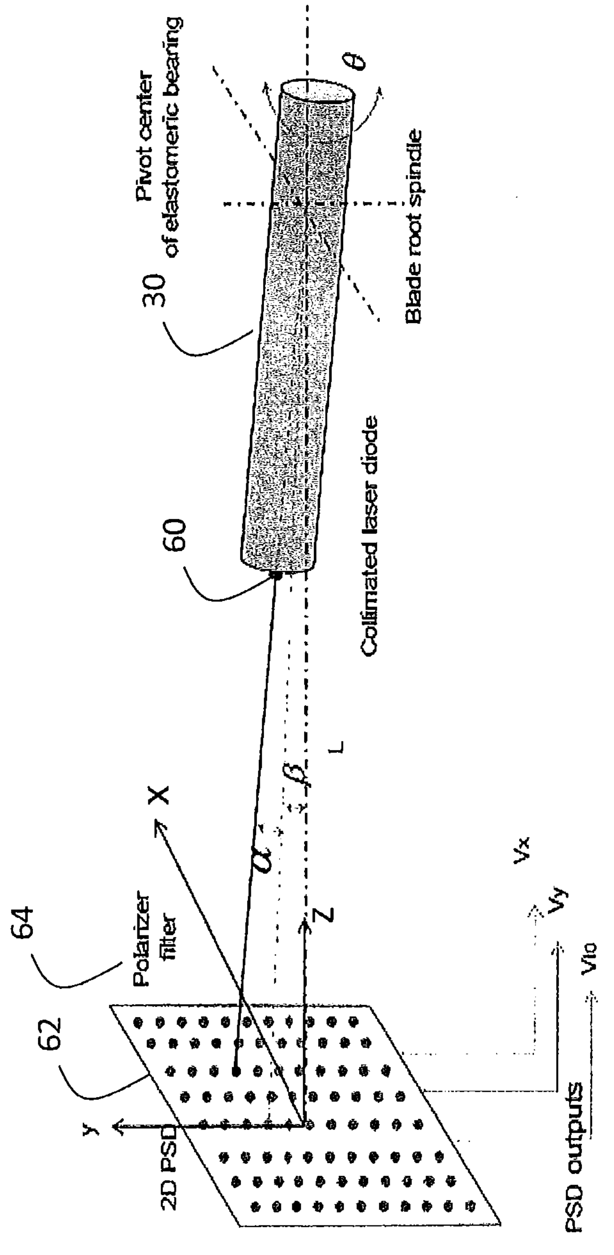
Pivot center
of elastomeric bearing
30
Blade root spindle
θ
Collimated laser diode
60
L
β
α
X
Z
64
Polarizer
filter
62
2D PSD
y
Vx
Vy
Vio
PSD outputs

FIG. 4

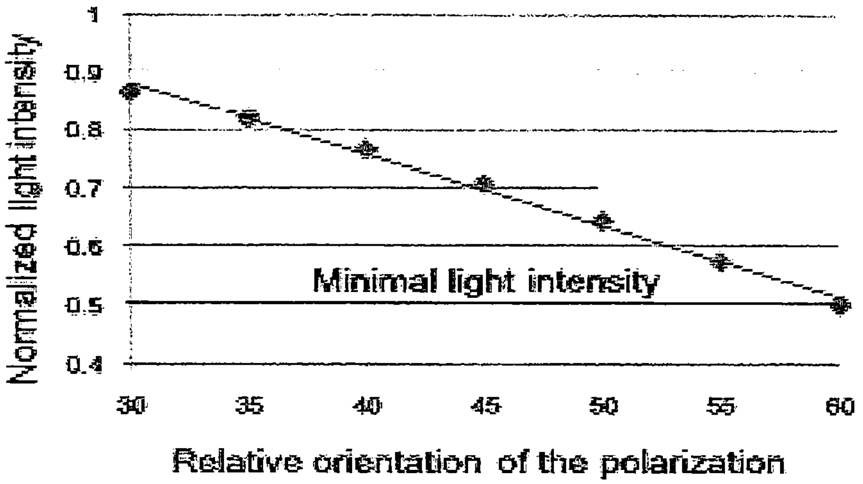
Normalized light intensity
1
0.9
0.8
0.7
0.6
0.5
0.4
Minimal light intensity
30
35
40
45
50
55
60
Relative orientation of the polarization

FIG. 5

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2010149602 A **[0003]**
- JP H10281750 A **[0003]**
- US 20100253569 A1 **[0003]**
- US 20110243730 A **[0003]**
- US 5137353 A **[0003]**